Securing America's Energy Future - The Role of Nuclear Energy and Argonne's Nuclear Program

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History of Argonne's Reactor Development

- Argonne's heritage in nuclear reactor research and development dates back to the beginnings of nuclear fission energy.
  - Chicago Pile-1 (CP-1) experiment under Enrico Fermi - Dec 2, 1942
  - Argonne designated the Center for Reactor Development: 1947
  - Experimental Breeder Reactor-1 (EBR-I): First electric power from nuclear energy in 1951
  - Early prototype research and demonstration reactors: Experimental Boiling Water Reactor, Chicago Pile No. 5, Experimental Breeder Reactor No. 2, etc, designed, built, and operated
- Argonne's reactor development has emphasized fast reactors.
- Integral Fast Reactor (IFR): 1984-1994
  - Advanced liquid-metal cooled fast reactor
  - Metal fuel and pyroprocessing

Argonne's Current Nuclear Energy Programs

- The electrometallurgical technology (pyroprocess) for treatment of DOE owned spent fuel. Demonstration of this key technology has been successfully completed at ANL-West, and application to EBR-II spent fuel is in progress.
- The Nuclear Energy Research Initiative (NERI) - R&D on innovative technologies and system concepts
- The Nuclear Energy Plant Optimization (NEPO) program - R&D to improve performance of the current nuclear energy plants
- The Generation IV Program - establish R&D activities for nuclear energy systems for deployment by 2030
- International Nuclear Safety - programs to improve the safety of Soviet-designed reactors in eastern Europe and the former Soviet republics

The Present Situation for Nuclear Power

- Nuclear energy is needed.
- Nuclear energy technology today:
  - is safe and reliable;
  - emits no greenhouse gases;
  - is not subject to short-term disruptions of fuel supplies.
- Our current nuclear plants are performing exceedingly well.

The Present Situation for Nuclear Power

- There are now 103 NPPs operating in the USA, and 435 world-wide.
- Nuclear energy is the source of about 20% of the US electrical generation, and a similar proportion world-wide. Some countries have a much larger fraction of nuclear-powered electricity (e.g., France, Belgium, Switzerland, Japan).
- Nuclear provides almost 70% of the US sources of emission-free generation.
- In 1999, nuclear power led to avoidance of about 27% additional carbon emissions from electricity generation.

The Present Situation (Cont'd)

- The nuclear power industry is achieving record levels of performance
  - 26% increase in output from 1990 to 1999; equivalent to output of 19 new 1000 MW plants
  - Operating plant capacity factor = 88.5% in 1999
  - For 1999, production costs for nuclear electricity were lowest of any major expandable source.
    - Nuclear: 1.83¢/kwh
    - Coal: 2.0¢/kwh
    - Oil: 3.18¢/kwh
    - Gas: 3.52¢/kwh

The Present Situation (Cont'd)

- License extension is a reality
  - Approved: 5 units (Calvert Cliffs 1, 2; Oconee 1, 2, 3)
  - Filed: 3 units (ANO 1, Hatch 1, 2)
  - Through 2001: 12 units expected to apply
  - 2002/2003: 14 units expected to apply
  - Eventually, 85% of the units are expected to apply for license extension.

- NRC is improving its processes for monitoring plant performance and focusing on safety-significant items

The Present Situation (Cont'd)

- Spent fuel is managed safely today using on-site wet and dry storage
  - Steady progress is being made on evaluation of Yucca Mountain as the national repository, but uncertainties exist in the ultimate outcome.

The Present Situation (Cont'd)

- The educational and scientific infrastructure supporting nuclear energy needs revitalization.
  - Aging staff; lack of new people entering the field
  - University nuclear engineering programs are disappearing
  - R&D and teaching facilities are closing
  - Danger of technology leadership moving overseas

Argonne's Role in Current Reactors

- Provide technical support to improve the efficiency and reliability of the current plants
  - DOE/EPRI Nuclear Energy Plant Optimization (NEPO) program.
- Provide R&D support to the USNRC on license extension issues
  - Materials behavior and aging effects are the focus.
- Work with plant staff, research institutes, and regulators to improve safety of Soviet-designed reactors, primarily in Russia, Ukraine, Armenia, and Lithuania.
- Provide education and training opportunities.

The Future of Nuclear Energy

- There is a massive need for increased electricity generating capacity
  - Current US capacity = 790,000 MW
  - New capacity needed by 2020:
    - at 1.4% annual demand growth = 300,000 MW
    - at 2.0% annual demand growth = 401,000 MW
- Nuclear must contribute to this new capacity.

The Future of Nuclear Energy (Cont'd)

- Advanced LWRs have received design certification in the US (AP-600, ABWR, System 80+)
  - Two ABWRs have been built in Japan.
  - Design variations are being developed.
- Evolutionary designs are being pursued in Europe.
- The South African "Pebble Bed Modular Reactor" has received considerable interest in some quarters in the US.

The Future of Nuclear Energy (Cont'd)

- US DOE programs are seeking innovative concepts and technology for a new "Generation IV" of reactors for post-2010 markets.
  - Nuclear Energy Research Initiative (NERI)
  - Generation IV Initiative
- Argonne is a major participant in these programs.

Argonne's Longer-Term Objective

- Development of an advanced reactor/fuel cycle concept that meets the following criteria, in order to maintain nuclear fission as a long-term energy option:
  - Sustainability - energy potential without resource limit
  - Safety based on passive characteristics inherent in the technology
  - Improved technology to better manage nuclear waste
  - Highly proliferation resistant reactor and fuel cycle
  - Economically competitive

1. Sustainability: Resource Extension

- A fast spectrum reactor with an innovative fuel cycle is the only system that can accomplish a full utilization of uranium resources.
  - Such a system can deliver 100 times the energy possible from available uranium resources in today's reactors.
  - Intrinsic nuclear characteristics are the reason for this improvement.

2. Passive Safety

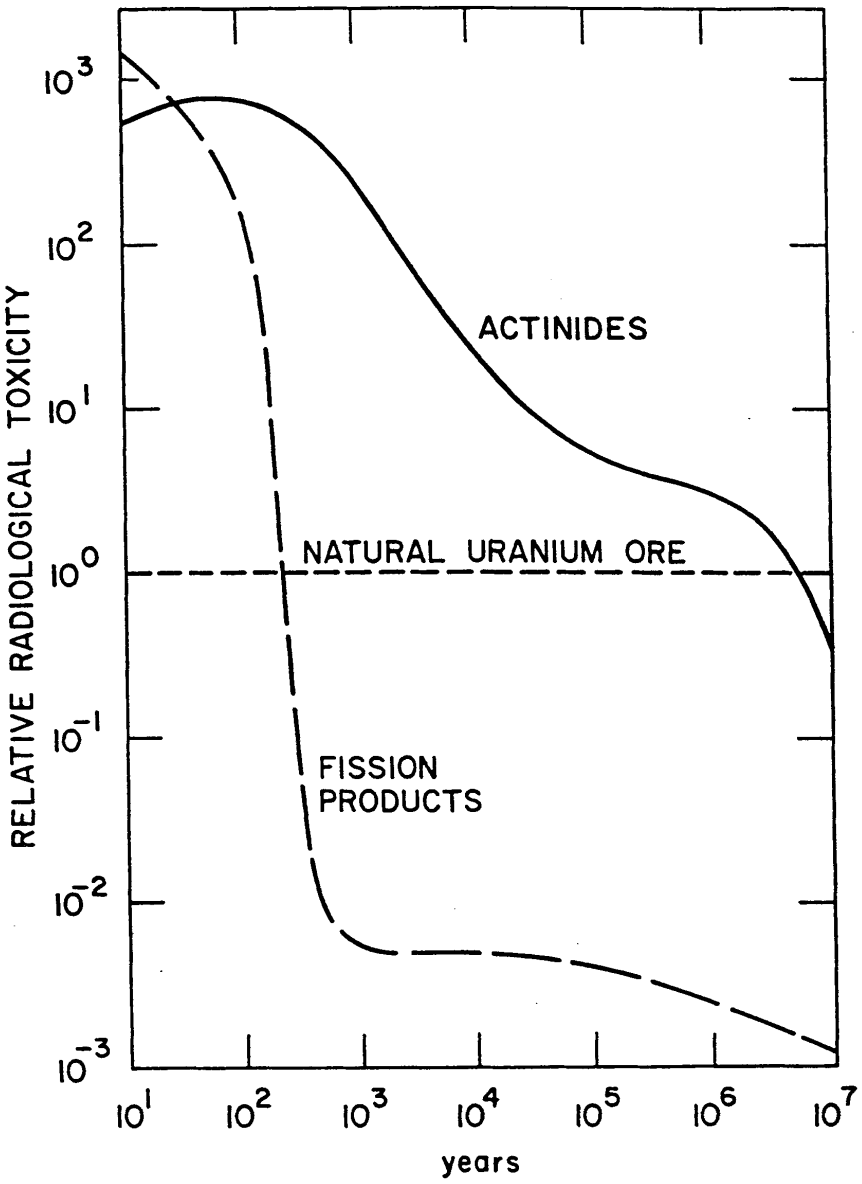
- The landmark tests conducted on EBR-II in April 1986 demonstrated the ultimate passive safety characteristics of the liquid metal cooled fast spectrum reactor, if properly designed.
  - Loss-of-flow without scram from full power
  - Loss-of-heat-sink without scram from full power

Key Safety Characteristics

- Low-pressure cooling system
- Large margin to coolant boiling temperature.
- Pool design provides thermal inertia.
- Overall highly negative reactivity feedbacks in undercooling transients.

3. Waste Management Solution

- Argonne's electrometallurgical technology can recover minor actinides along with plutonium and recycle them back into the reactor for in-situ burning, at the same time generating energy.
  - Recycling eliminates long-term toxicity of the waste, thereby reducing the lifetime of the waste from millions of years to few hundreds of years.
  - Technical performance requirements of the repository are greatly reduced.


RELATIVE RADIOLOGICAL TOXICITY
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ACTINIDES
NATURAL URANIUM ORE
FISSION
PRODUCTS
10^1
10^2
10^3
10^4
10^5
10^6
10^7
years

4. Nonproliferation Characteristics

- Once-through (no recycle) fuel cycle is commonly perceived as the best option.
- Argonne's electrometallurgical technology provides a technical solution:
  - The process cannot separate a pure Pu product that is directly usable for weapons.
  - The product (some U, Pu, minor actinides, some fission products all combined) is highly radioactive and, hence, self-protective.
  - The product can be immediately converted to reactor fuel in the hot cell facility.

5. Economics

- Economics of the next-generation reactor should be compared with alternative energy options in the longer term (2020 and beyond), although boundary conditions for this longer term economic assessment are not well quantifiable at this time.
- Sodium cooled reactors have demonstrated long-life reliability.
  - EBR-II steam generators operated without a single tube leak for over 30 years.
- Electrometallurgical technology promises major improvements in fuel cycle costs.